CONVERSION OF AlGaAs INTO InGaP EMITTER HBT RF ICs FOR IMPROVED MANUFACTURABILITY

H.-F. Frank Chau, Zhengming Chen, N.-L. Larry Wang, Xiaopeng Sun and Barry Lin

EiC Corporation
45738 Northport Loop West, Fremont, CA 94538, U.S.A.
Email: fchau@eiccorp.com

ABSTRACT

The InGaP emitter HBT technology is rapidly emerging as the dominant HBT technology because of its recognized better manufacturability, transistor reliability, and current gain stability over current and temperature than its AlGaAs emitter counterpart. Although the majority of commercial HBT products are still based on the AlGaAs emitter HBT process, we demonstrated that a direct drop-in replacement of the AlGaAs HBT process with an InGaP HBT technology was possible without affecting much the circuit performance simply by changing a few steps in transistor processing. In addition, we showed that our InGaP emitter HBT process was indeed a more manufacturable process as evidenced from the improved uniformity across a four-inch wafer, high yields and tight distributions of electrical characteristics of our HBT devices and circuits.

INTRODUCTION

The AlGaAs emitter HBT process has long been the mainstream technology for HBT power amplifiers, broadband amplifiers and other HBT RF ICs in the commercial market. In recent years, however, the InGaP emitter epi and process technology has matured to the point that it appears ready to take over its AlGaAs emitter counterpart to become the dominant HBT technology. There are many advantages associated with this InGaP over the AlGaAs emitter HBT system. The near-one-order-of-magnitude improvement in transistor life times over AlGaAs emitter HBTs has been reported elsewhere [Yeats et al. (1)] and is not discussed further here. The improved transistor reliability leads to higher current handling capability of devices and therefore potentially smaller die size. Another key driving force is potentially better manufacturability for improved uniformity and yield, and more stable electrical characteristics of circuits over current and temperature. From a company's standpoint, a key issue is how to make the transition smoothly from the AlGaAs to InGaP emitter process without affecting the electrical performance of existing products, and transparently to circuit designers and customers.

We have developed a manufacturable InGaP emitter HBT process suitable for the production of HBT RF components. In the following sessions, we demonstrated that a direct drop-in replacement of the AlGaAs HBT process with an InGaP HBT technology was possible without affecting much the circuit performance simply by changing a few steps in transistor processing. We showed that the InGaP process was indeed more manufacturable with improved uniformity and high yield.

EPI DESIGN AND PROCESS CONVERSION

An InGaP emitter HBT typically shows a slightly higher dc current gain than an AlGaAs emitter HBT of similar epi structure and size. One reason is the increased suppression of hole injection from the base into the emitter layer due to the larger valence band offset at the InGaP/GaAs emitter-base heterojunction. Another reason is the use of a lower surface recombination InGaP emitter ledge. These give rise to the stable DC current gain of InGaP HBTs over temperature and decades of current density. The latter is demonstrated in the measured gummel plots shown in Fig. 1.

Our goal was to make the process conversion from AlGaAs to InGaP emitter technology transparent to circuit designers. The first step was therefore to reduce the current gain to a value comparable to that in AlGaAs HBTs in the current density range of interest. This can be achieved by slightly increasing either the base layer thickness or doping concentration, or both. The required modification in the base epi structure was small and affected only slightly RF characteristics of the transistor, particularly in the low frequency range. As shown in Fig. 2, our InGaP emitter HBTs showed a current-gain cutoff frequency of 41 GHz, and a maximum stable gain of 15.7 dB at 8.5 GHz, in comparison with 37 GHz and 16.1 dB respectively in the AlGaAs transistors of the same size and bias conditions. The corresponding maximum DC current gains were 115 and 100, respectively.

To demonstrate that the conversion to our InGaP emitter HBT process was indeed transparent to circuit designers, we used the same set of mask layers designed for an AlGaAs cellular band power amplifier (PA) to fabricate an InGaP version of the amplifier. The only exception to one mask layer was to account for the difference in etch undercut in transistor processing as a result of the different etching properties on the InGaP and AlGaAs emitter layers. For a fair comparison, we modified only that particular mask pattern in such a way that the resultant mesa dimensions between the two process technologies were the same. As shown in Table 1, under the CMDA test conditions at 836 MHz, the unoptimized InGaP emitter PA exhibited a slightly higher gain of 32.7 dB versus 30.0 dB in the original AlGaAs design. The ACPRs and supply currents were very similar in both cases. Under the CW test conditions at the same frequency, the unoptimized InGaP HBT PA showed a slightly higher Psat of 32.1 dBm and a better efficiency of 52.1 %, in comparison with 31.5 dBm and 48.0% respectively in the AlGaAs version. The overall difference in the performance was, however, small.

MANUFACTURABILITY CONSIDERATIONS

Despite the small differences in the performance of transistors and circuits, the advantages of the InGaP emitter process are, however, prominent from the manufacturing viewpoint. Because of the presence of wet chemical etchants of extreme selectivities over InGaP and GaAs in the InGaP HBT process, excellent etch control can easily be achieved for the formation of the critical emitter ledges and the base reveal etch. The uniformity in transistor characteristics was improved across a 4” wafer. As illustrated in Fig. 3, for example, the standard deviations of the measured maximum current gain and base-to-base resistance in our specially designed split-base, $2 \times 6\ \mu m^2$ HBT test structures were reduced to 2.2 % and 1.6 % respectively of their means, from 2.6 % and 2.1 % respectively in the AlGaAs emitter process.

The improvement in uniformity resulted in high DC yields of InGaP HBT circuits. Our InGaP emitter HBT broadband amplifiers, for example, reached a DC yield of over 96% with a very tight distribution of electrical characteristics. Near 99% of the passed circuits had their measured voltages sensed at the output stages under constant current bias at the inputs fell within $\pm$ 0.1 V of their target operation voltage of 5.0 V.

SUMMARY

We demonstrated that a direct drop-in replacement of the AlGaAs HBT process with an InGaP HBT technology was possible without affecting much the circuit performance simply by changing a few steps in transistor processing with improved uniformity and high yield. The proven straightforward transition from AlGaAs to InGaP products without major redesigns in circuits, demonstrated good manufacturability, good uniformity and high yields, coupled with other intrinsic advantages of InGaP emitter HBTs, such as better transistor reliability, a relatively constant DC current gain over temperature and decades of current densities with no extra epi wafer and processing cost, will make the InGaP emitter HBT process the dominant HBT IC technology in the near future.

ACKNOWLEDGMENT

The authors would like to thank the technical support of Amelia Chen, Christine Chiu, Remy Crescini and Sindolfo Gacayan, Grace Lee, Huan Nguyen and Edelwina Rivas.

REFERENCES

(1) Bob Yeats et al., "Reliability of InGaP-Emitter HBTs", *Int. Conf. GaAs MANTECH*, pp. 131-135, 2000.

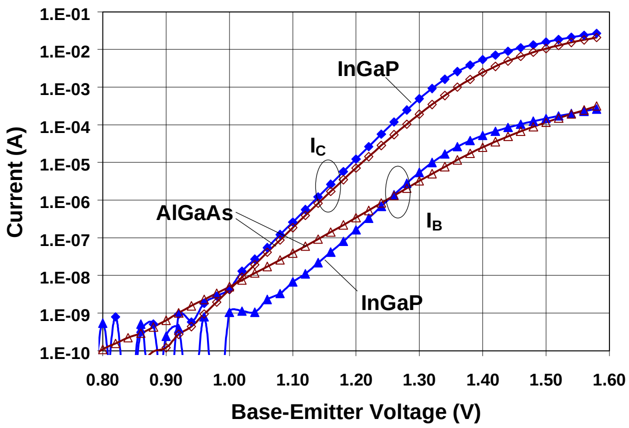

Fig. 1. Comparison of measured gummel plots of 2×6 μm^2 AlGaAs and InGaP emitter HBTs.

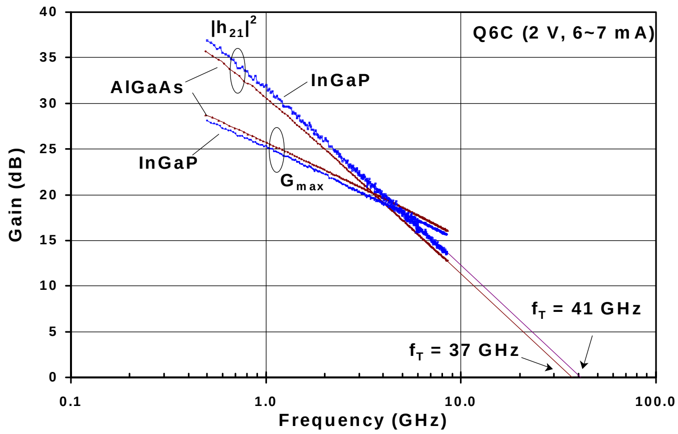

Fig. 2. Comparison of measured small-signal RF characteristics of 2×12 μm^2 AlGaAs and InGaP emitter HBTs.

Parameter	**AlGaAs Emitter HBT PA**	**Unoptimized InGaP Emitter HBT PA**
CDMA Conditions:		
Po (dbm)	28	28
Gain (dB)	30.0	32.7
ACPR1 (dBc)	-44	-44
ACPR2 (dBc)	-56	-58
Ic (mA)	520	550
CW Conditions:		
Psat (dBm)	31.5	32.1
η (%)	48.0	52.8
Ic (mA)	900	878

Table 1. Performance comparison of an AlGaAs and an unoptimized InGaP emitter HBT power amplifiers fabricated with a mask designed for the AlGaAs emitter HBT process. Frequency = 836 MHz, Vcc = 3.5 V, Vpd = 3.0 V.

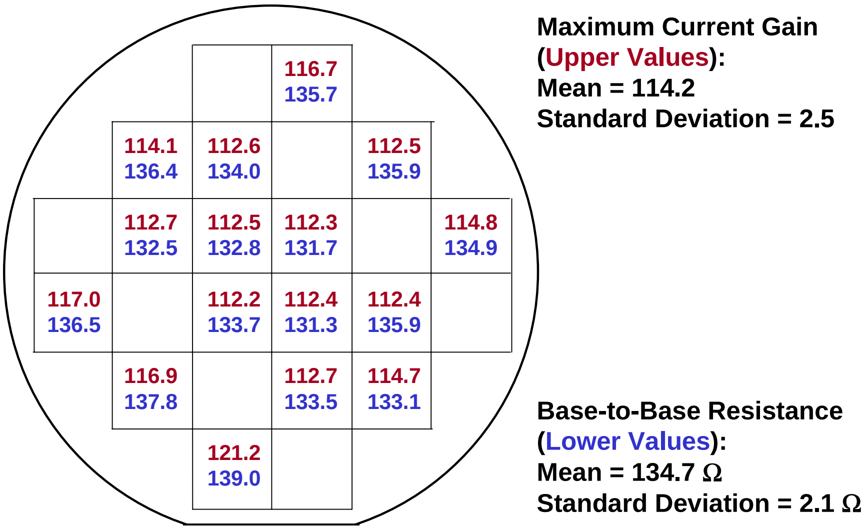

Fig. 3. Uniformity of maximum current gains and base-to-base resistances measured in $2 \times 6\ \mu m^2$ split-base InGaP emitter HBTs across a 4” wafer.

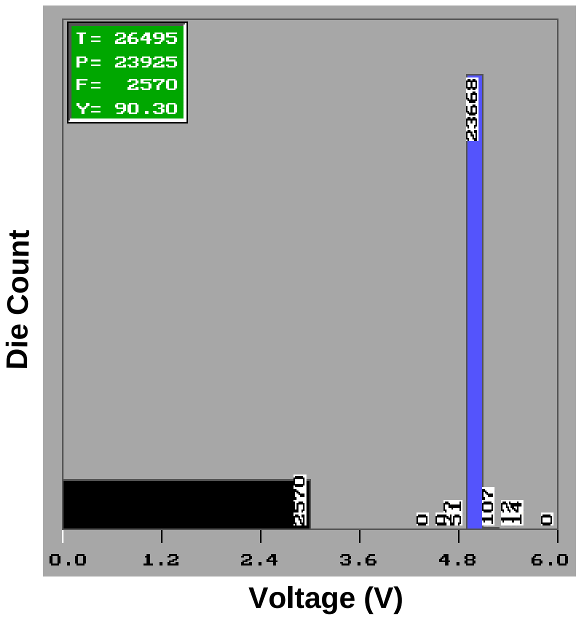

Fig. 4. Uniformity of DC voltages measured at the output sides of InGaP emitter HBT broadband amplifiers under constant current bias at the inputs. Excluding the die in the exclusion zone at the edge of wafer, the DC yield of these broadband amplifiers reached 96.2%.